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Reclamations – Case Studies

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ABSTRACT

Increasing demands for urban water fronts and the need for continually operational airports coupled with shortages of land spaces has led to the growth of lands reclaimed from the near and off-shore regions of the world. Case histories of reclamations of recent times in the east, especially in Japan, Hong Kong, Korea, Singapore, etc. are reviewed. The paper also reports the methods of reclamation, the improvement of reclaimed ground and examples of observed settlements in typical cases.

INTRODUCTION

The origins of several civilizations can be traced to deltas and coastal regions for obvious reasons of availability of fresh water and maritime trade. About eighty percent of the major metropolis with the largest populations are presently located (Miura et al. 1994) in these areas, e.g. Bangkok, Boston, Cairo, Hong Kong, Kolkata, Mumbai, New York, Rio de Janeiro, Shanghai, Singapore, Tokyo- Hiroshima, etc. Historically, the major part of the Netherlands and the city of Boston are classic examples of reclamations. The earliest recorded reclamations have been in Netherlands and Saga, Japan. Minor reclamation took place along the shoreline in Hong Kong in 1841 (Kao et al. 1998). Medium scale reclamations took place in Tokyo during 1860-1960 but large-scale reclamations started from about 1945 (Hamasuna et al. 1991).

Increasing demands for the urban waterfronts is forcing traditional activities such as port terminals, water access dependant industries, transportation systems, etc. on to the near shore areas. The need for fresh lands close to the above and other rapidly developing cities requires reclamations of lands from near and offshore regions. The spectacular reclamations for port cities of Yokohama and Kobe, Changi (Singapore), Incheon (Korea), Kansai (Japan) and Chek Lok Kok (Hong Kong) airports are the most recent examples. Man-made islands requiring reclamations have also been built in the Arctic. Table 1 summarizes some of the recent reclamations.

Table 1 Comparative Study of Several Reclamations

Location	Area, ha	Depth of Water, m	Fill Vol. Mm^3	Settlement m
Ohgishima Island	51.5	5.0	85	-
Kansai I Japan	510	16.5 - 19.0	-	14.0
Kansai II, Japan	800	16.5 to 19.0	-	-
Nakagusuku, Japan	340	4.0 - 5.0	-	2.5 - 3.0
New Kita Kyushu Airport Japan	375	13.0	-	-
Chep Lok Kok Airport, Hong Kong	920	-	206	-
Kolkata, India	800	1.5 - 2.0	-	0.3 - 0.4
Incheon Airport, Korea	56	2.0-6.0	-	0.3-0.5
Changi Airport I, Singapore	645	-	40	-
Changi Airport II, Singapore	1550	-	210	-
Changhua Ind. Park, Taiwan	3600	-	147	-
Mailao, Taiwan	2250	-	74	-
Malaysia	70,000	2.0 to 10.0	-	-
Philippines	9,000	-	-	-

RECLAMATION IN KOLKATA

About 8 sq. km. area had been reclaimed in Kolkata from land previously used as fishponds by hydraulically filling it with Hooghly sand. (Dastidar 1973). The subsoil consisted of 4 to 5.0 m thick very soft clay. The height of reclamation varies over an average value of 1.75 m. In one of the major and first ground

improvement works, the ground was treated with vertical drains and preloading to make it serve as an adequate subgrade to support shallow foundations. This was the same project in which sandwicks were used for the first time. The improvement measures obviated the need to provide deep foundations to avoid 30 to 40 cm settlements due to construction f two to four storied residential structures and just added a mere 6% to the over all cost of the buildings.

RECLAMATIONS IN JAPAN

Japan consists of group of islands extending from Hokkaido in the north to Okinawa in the south. Its topography is such that only one fifth of the land area is available for agriculture, residential, commercial and industrial applications. Therefore reclamation of land from near shore areas has become imperative. The growth of reclaimed area starting from mid 1950s is shown in Fig. 1 while the distribution of the same across the country is depicted in Fig. 2. The major reclamations are concentrated in the Honshu island making Tokyo to Hiroshima a mega metropolitan area.

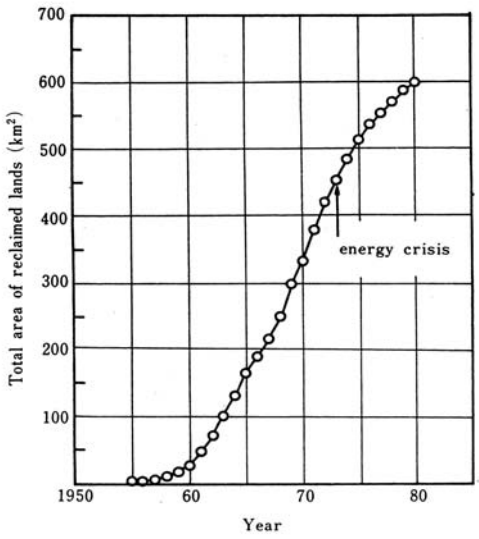

Fig. 1 *Total area of reclaimed lands since 1953 (after Ad Hoc Com. 1977)*

Ohgishima Island

The Ohgishima island extending over an area of 51.5 ha is a large-scale reclamation project involving 85 Mm^3 of fill for a steel mill complex in the Tokyo Bay.

Kobe Port Reclamations

Reclamations for Kobe Port have been extensive. Rokko and Port Islands are two major islands created out of reclamation

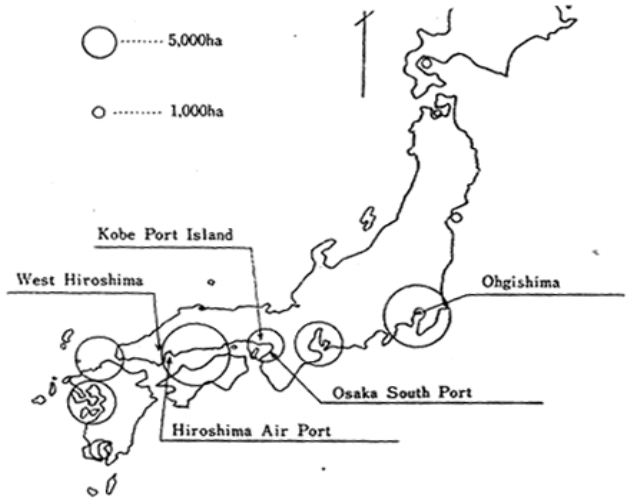

Fig.2 *Locations and area of major reclaimed lands Developed since 1968 (after Ad Hoc Com. 1977)*

apart from city areas for hospital, highways and other facilities. The total area of reclamation is 436 ha while the fill volume is of the order 80 Mm^3 (Fig.3).

KANSAI INTERNATIONAL AIRPORT ISLAND RECLAMATION

The Kansai International Airport is the first offshore airport in the world. It is built on an island 511.0 ha in area in water depths of the order of 16.5 to 19.0 m and at a distance of 5.0 km from the coast of Senshu in Osaka Bay. Fig. 4 depicts the profile of reclamation. The reclamation was preceded by the installation of 400 mm dia. sand drains throughout the area at spacing varying from 1.6 to 2.5 m. The effective grain size for the sand drains were 0.3 to 0.4 mm. The sequence of dumping was initially by direct dumping from bottom hopper dredges and subsequently by the soil unloaded. Stability was achieved during construction by a six-month delay between stages 2 and 3. A minimum factor of safely 1.2 was maintained against stability failure.

The reclamation for phase II of the Kansai Airport is more extensive and challenging as it covers a much larger area than in Phase I and extends much farther in to the sea. A schematic along with the cross section of the seawall are depicted in Fig. 4. Sand placement for the sea wall and for the reclamation were performed by bottom-open barges. The seabed once again was improved by sand drains. Settlements of the order of 5.0 to 6.0 m were observed in the first 600 days for the sea wall constructed. An innovative feature of this project is the use of CPT and bathymetric data for construction control.

Trans Tokyo Bay Highway

One of the interesting applications of reclamation is for the abutments and intermediate piers for the Trans Tokyo bay Highway connecting Kawasaki in Kanagawa, to Kisaraju in

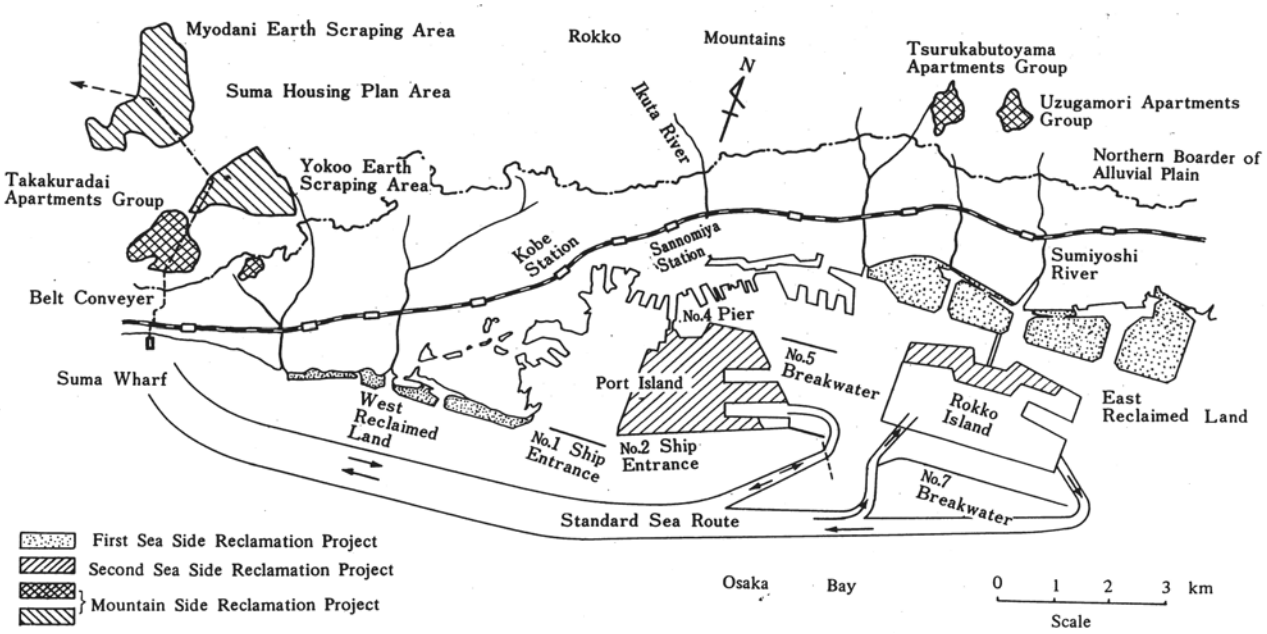

Fig. 3 Reclamation projects in Kobe Port (after Ad Hoc Com. 1977)

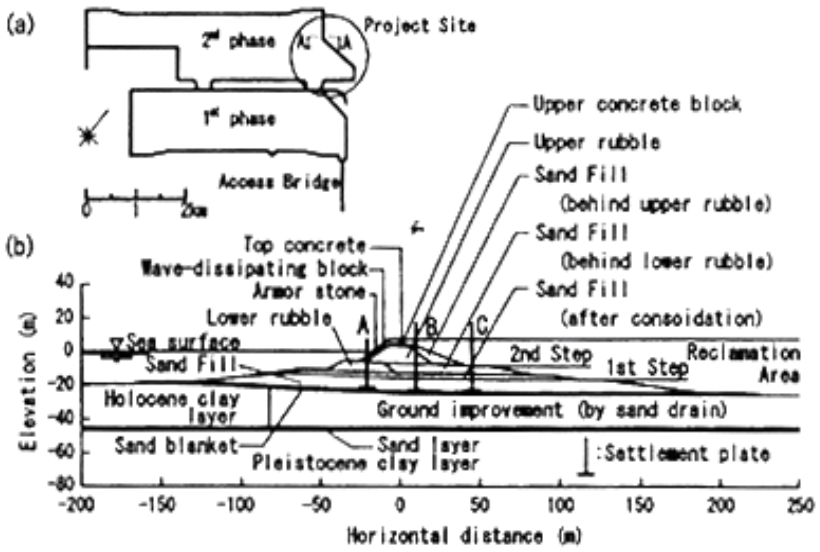

Fig. 4 Plan of KIA, location of project and typical cross section of seawall (after Fukusawa et al. 2003)

Chiba, over a distance of 15.1 km. While the Ukishima reclaimed ground abuts the Kawasaki side of the bridge, the Kawasaki and Kisarazu man made islands are developed for the construction of tunnels and the bridge (Fig. 5). The Deep Mixing Method (DMM) was used to improve the soft seabed material to reduce the settlements due to loading from the reclamation and to stabilize the soil for tunnel excavation.

Nakagusuku Bay Harbor Project

Nakagusuru Bay Harbor is located at the East coast of the middle Southern part of Okinawa Island. A new harbor project involved reclamation (Fig. 6) of about 340 ha of land by dumping of about 10,500 m^3 of dredged soil. The reclaimed soils contained more than 90% of silty clay at a water content in the range 150 to 300%. The reclaimed layers (4.0 to 5.0 m thick) were reinforced

by geonets while the seabed more than 20.0 m thick was improved by strip drains.

INCHEON INTERNATIONAL AIRPORT, KOREA

The Incheon International Airport is built by reclaiming the tideland between Youngjong and Yongyoo islands close to the city of Incheon covering an area of 56 Mm^2. The reclaimed ground is underlain by an upper marine clay 8.0 to 10.0 m thick and an alluvial layer that extends to a depth of 25.0 m. Sand seams 5.0 to 20.0 cm thick are interspersed within the marine clay layer. Sand drains (SD), plastic board drains (PVD), pack drains and sand compaction piles (SCP) were used to improve the in situ ground conditions. Interestingly all these methods led to similar improvements in the ground.

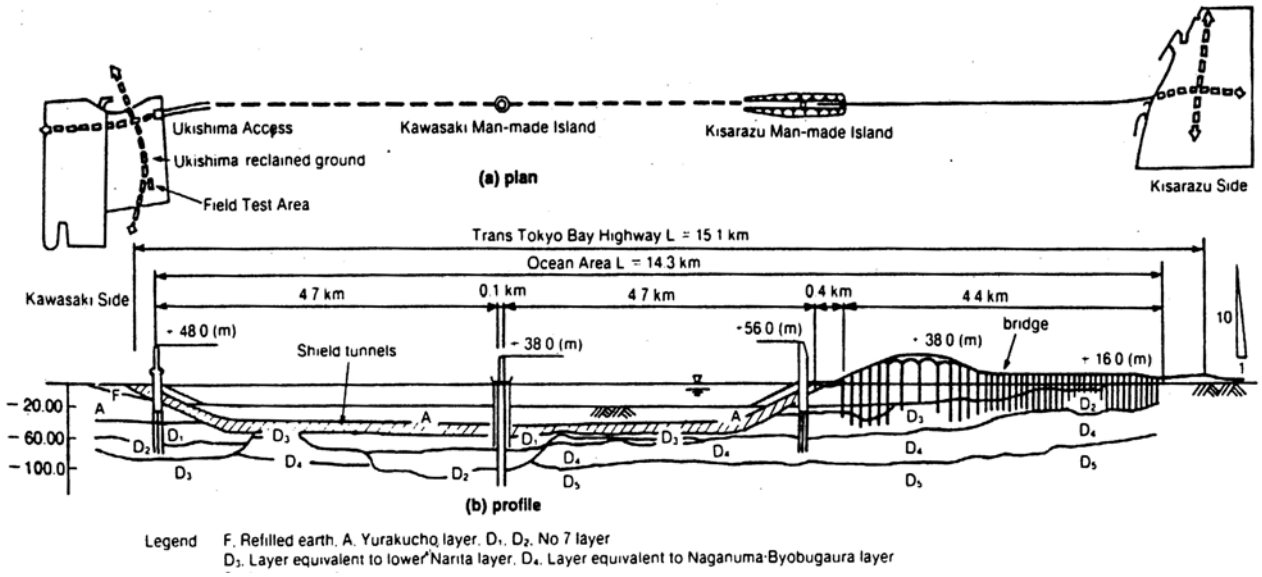

Fig. 5 General plan of the Trans Tokyo Highway (after Wasa et al. 1991)

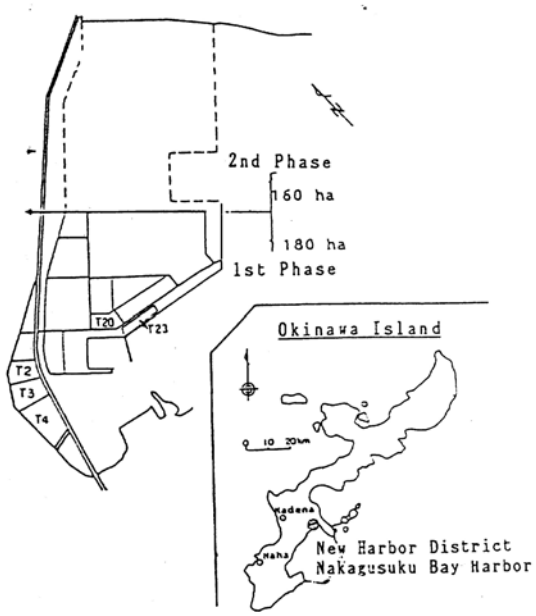

Fig.6 Location of project area (after Uehara et al. 1991)

The Gateway Arterial Road, Brisbane, Australia

The Gateway Arterial Road connects the National Highways North and South of Brisbane. Much of the northern section of the arterial road traverses flat, low lying, coastal alluvial terrain with occasional infilled stream channels with up to 20.0 m thick soft marine clays/silts (Litwinowicz and Hobbs 1991). Several foundation treatments, e.g. vertical drains, stone columns and basal reinforcement of embankments were effected at this site for the in situ soil and the reclaimed ground.

Reclamations in Malaysia

Several reclamations have been planned and some completed in Malaysia (Aun 1998) covering a total area of 70,000 ha and in water depths ranging from 1-2.0 m in Kuchinbg Industrial Estate to 8.0 to 10.0 m in Lekir and Badah Datoh area in Perak.

Reclamations in Philippines

Reclamations in Philippines have and are taking place in Manila-Cavitas Coastal, Laguna de Bay and Cebu regions (Wang 1998). While the first one is along the coast the other two are inland covering areas of 3000 and 2640 ha respectively.

Asaluyeh Oil Complex, Iran

Asaluyeh is located in south west of Iran on the coastal zone of Zagos oil field along the Persian Gulf. Part of the project area is reclaimed from sea from a maximum depth of -14.0 m to an elevation of +3.0 m (Heidari and Gitipour 2003). The total fill volume was 60 Mm^3.

METHODS OF DUMPING

Various approaches are available for placing the soil in the process of reclamation. Soil is placed directly and spread with the aid of dozers if the water depths are relatively small, e.g. 1.0 m or less. The necessity of using barges without and with bottom hoppers increases with increasing water depths. Thus in case of Kansai International Airport reclamation, the first phase of reclamation was by soil placed through bottom hoppers. In most of the reclamations only granular material is used. However, where such material is not freely available as in reclamations in Singapore, a mixture of sand-clay system was tried (Lee et al. 1987). Sand is spread in thin layers over soft cohesive soils to accelerate the settlements and to also improve the strength of the top layers of the slurry. The sand when spread thinly either is arrested at the interface or gets penetrated into the clay. Thus a composite sand-clay system gets developed.

The behavior of this composite sand-clay system depends on the method of deposition, thickness and grain size of the sand spread, the height of supernatant water and the strength of the cohesive soil below. The density profiles at a typical location are shown (Fig.7) as effected by the thickness of the sand layer. The formation of a sand layer with a density of about 1.8 Mg/cu.m. can be noted confirming that the sand did not penetrate in to the soft slurry below. The increase in the density of the clay slurry partly due to sand penetration and partly due to consolidation under sand loading can be observed in Fig. 7. The density increases from an initial value of 1.15 Mg/cu.m. to as high as 1.8 Mg/cu.m.

Two types of lightweight materials composed of dredged clay and foam or beads are increasingly being used in Japan as fill material in reclaimed areas (Tsuchida and Kang 2003). The slurry of dredged soil is mixed with stabilizing agent and air foam or expanded polystyrol (EPS) beads of diameter 1 to 3 mm The unit weight of the material is as low as 10 to 11.0 kN/m^3 thus significantly reducing the overburden stress on and settlement of the sea bed. The undrained shear strength of these materials ranges between 200 to 400 kPa. This type of lightweight treated soil (LWTS) has been used in the repair of Kobe port after the Great Hanshin-Awaji Earthquake, Kumamoto Port, Ishikari Bay Port and the Tokyo International Airport reclamations.

ENGINEERING OF RECLAIMED GROUND

The seabed material consists either of soft to very soft marine clays or alluvial deposits. A typical geotechnical profile from Osaka bay (Fig. 8) illustrates highly plastic nearly normally consolidated clay with clay content in the range of 40 to 50%, liquidity index greater than 1.0, and undrained strength increasing at the rate of 13 kPa/m with depth. The range of variation of the relative density of filled granular material often lies in the range of 40 to 60% (Fig. 9).

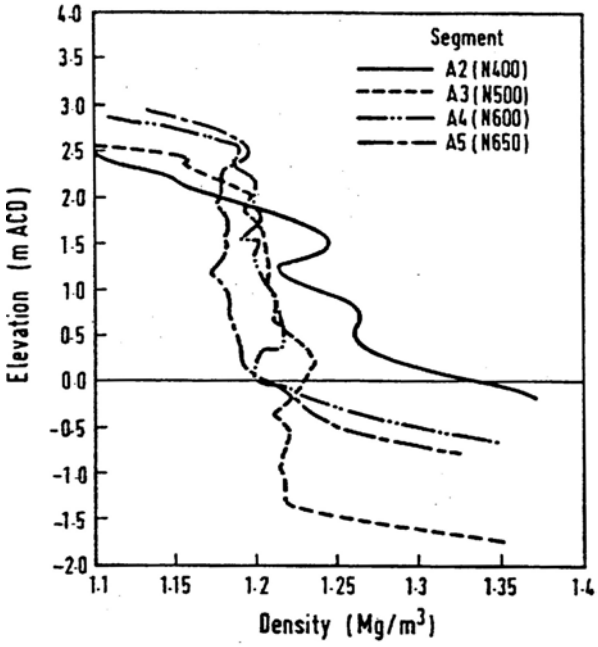

Fig. 7 Density of clay in A2 to A5

Consequently both the in situ soil and the reclaimed ground require improvements in their engineering properties. Traditionally, replacement used to be the obvious choice. Subsequently, several ground treatment technologies have been implemented (Fig. 10) such as vertical drains (sand or plastic board), sand compaction piles, Vibro compaction or vibro-rod techniques. Deep Mixing Method has become the preferred choice in the last 15 to 20 years.

The efficacy of various densification methods is compared in Fig. 11. Vibro-rod and vibro-compozer methods have performed better with post-treatment N-values in the range of 30 to 40 compared to the values of 15 to 20 for vibro-flotation. Umezaki et al. (2003) report the application of the Radio-Isotope (RI) Cone Penetrometer for the study of reclaimed area of the Island City in Hakata Bay in Fukuoka Bay. The validity of using RI Cone in estimating both the e-log σ' and undrained strength of the soils was clearly established.

SETTLEMENT OF RECLAIMED GROUND

As a consequence of reclamation and subsequent construction of infrastructures built over them, the in situ soft sediments/soils undergo large settlements. The magnitude of settlements varies with the depth of reclamation and the types of structures built upon the reclaimed ground. While Dastidar (1973) estimated

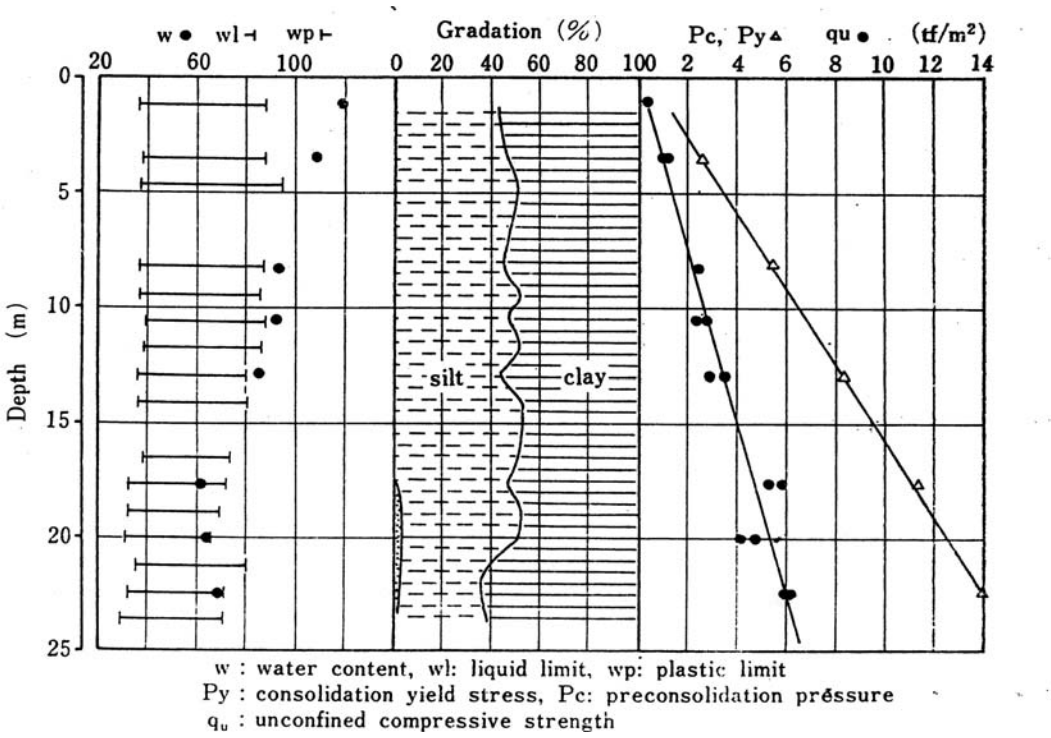

Fig .8 Typical geotechnical profile for high plastic marine clay found in the Osaka Bay

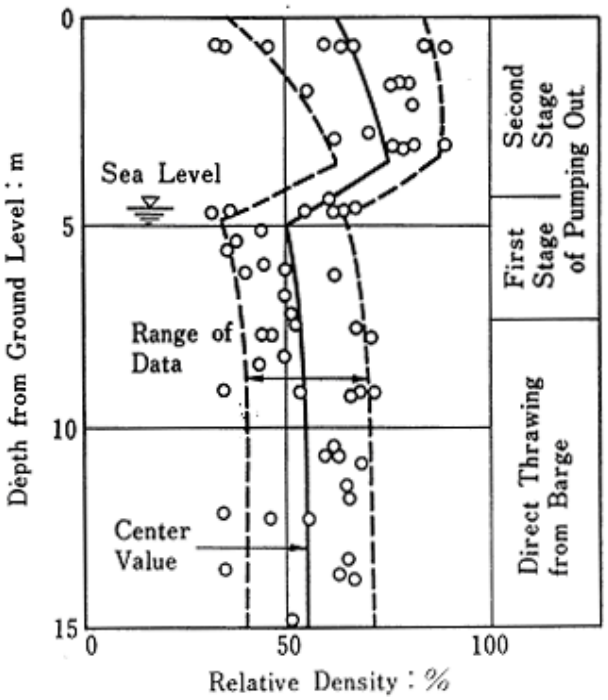

Fig. 9 Distribution of relative density of fill sand with depth (after Ad Hoc Com. 1977)

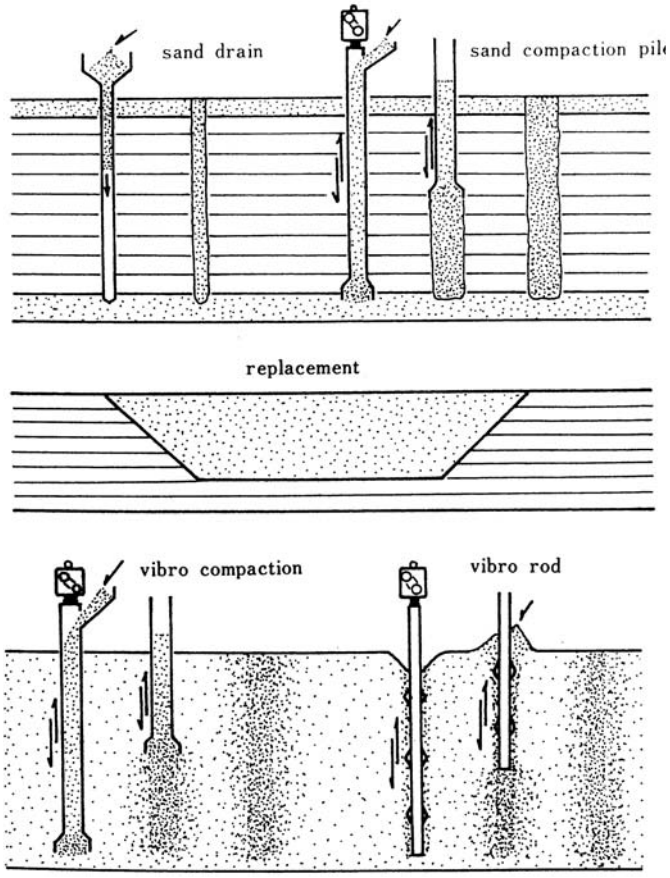

Fig. 10 Illustration of soil improvement methods forcClay and sand described in the case history (after Ad Hoc Com. 1977)

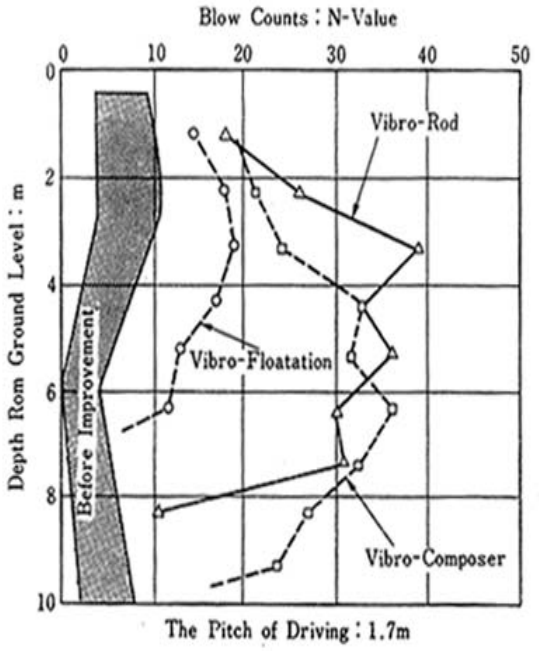

Fig. 11 Comparison of N Values of filled sand treated with various compaction methods (after Ad Hoc Com. 1977)

mere 30 to 40 cm settlements due to 2.0 m reclamation and construction of light to medium heavy structures, settlements of the order of 14 to 15.0 m are reported in the case of Kansai airport. where the depth of reclamation from out of the sea is of the order of 18.0 m. Mimura et al. (1990) report settlements of the order of 4.0 m in case of Koshien reclaimed ground where the depth of reclamation was about 12.0 m and an expressway was built over it. Soil layers till a depth of 83.0 m were considered for estimating the settlements. The process of construction and the progress of settlements are depicted in Fig. 12.

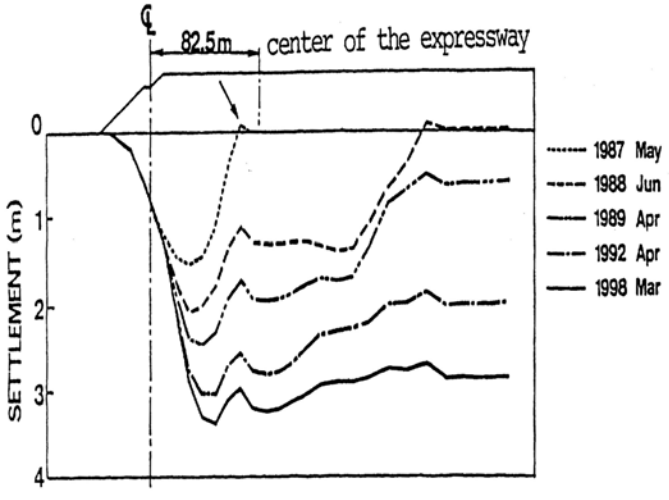

Fig. 12 Settlement profiles of the seabed (after Mimira et al. 1990)

CONCLUSIONS

Reclamations have been a real source for the development of agricultural and commercial activities and communities in earlier times and of late, for development of infrastructure and various other needs such as twenty-four hour airports. The pace of reclamation is now directly correlated with economic development of the region. Several projects have been completed and many more are under various stages of completion. The paper presents case histories of some major reclamations in Hong Kong, Japan, Korea and Singapore. The methods of reclamation and methods of treating the in situ ground prior to reclamation are also discussed.

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